COMPLETION OF THE INSTRUMENTATION FOR THE INVESTIGATION OF IMPACT STRESSES USING THE PHOTOELASTIC TECHNIQUE

WILLIAM J. FRANCY AND
CHARLES J. FORQUER

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BY

William J. Francy, B. S., B. C. E.
and
Charles J. Forquer, B. S., B. C. E.

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A C K N O W L E D G E M E N T

The authors wish to express their appreciation to Professor A. A. K. Booth for the assistance he has rendered to the project as a whole, and to express their heartfelt thanks to Mr. Frank Hicks for his unselfish aid in the design, testing, and operation of the electrical units. We also wish to thank the entire staff of the Institute with whom we came in contact for their ungrudging aid and cooperation.

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INTRODUCTION

This thesis is a continuation of the work commenced by Messrs. Burke and Munninger in their thesis of June, 1948. The scope of this thesis is thoroughly discussed in the introduction and analysis of their thesis. For a thorough understanding of the entire project, it is suggested that the work of the above authors be studied in conjunction with this thesis.

OBJECT

The object of this thesis is to complete the instrumentation for a photoelastic study of impact stresses commenced by Messrs. Burke and Munninger, and to prove that the proposed method of study is both feasible and practical.

INSTRUMENTATION

GENERAL DESCRIPTION OF TECHNIQUE

The equipment used in this work consists of the following:

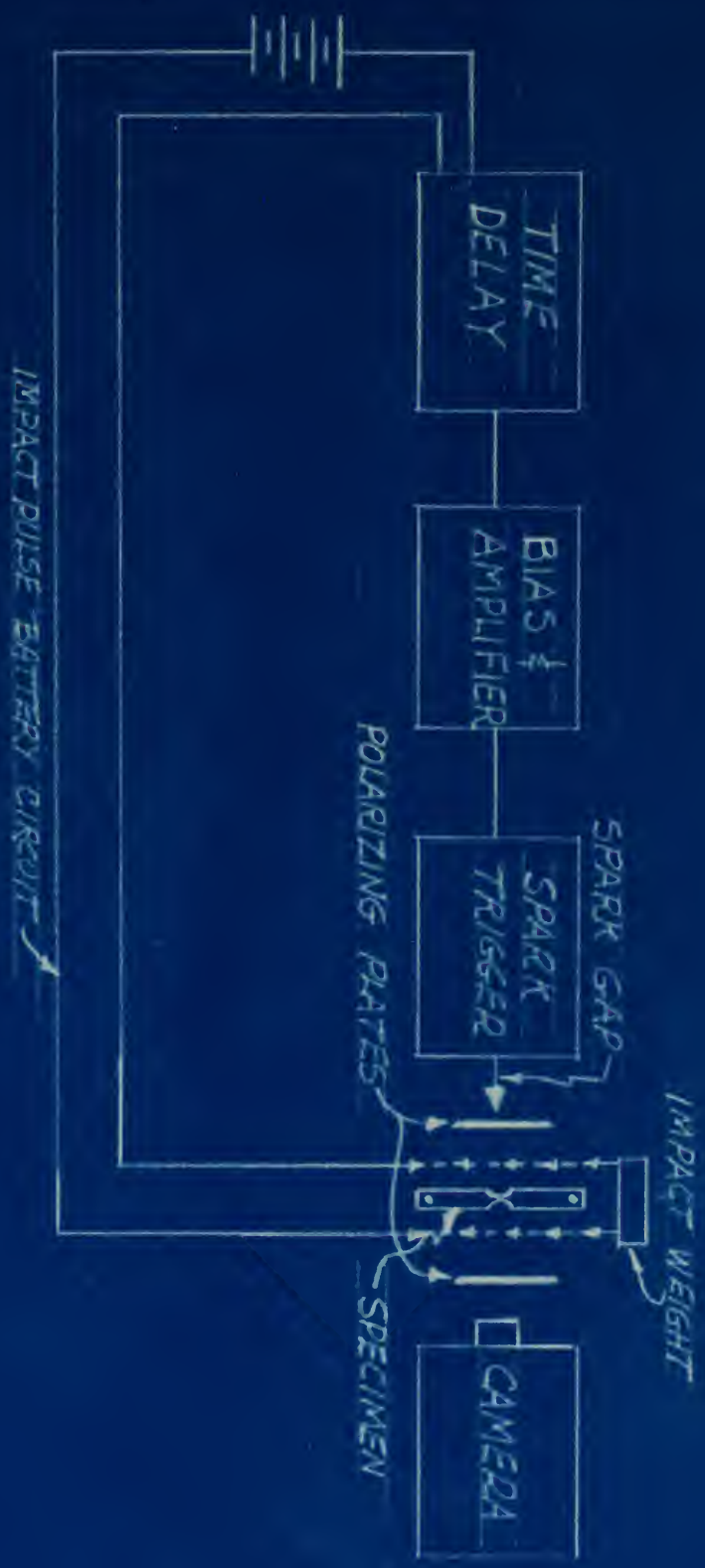
1. Weight dropping mechanism
2. Light source with controls (Electrical Units)
   a. Time Delay
   b. Bias and Amplifier
   c. Trigger Unit
   d. Sparking Unit
3. Optical Unit
   a. Focusing Lens
   b. Polarizing Plates
   c. Specimen
   d. Camera

This apparatus furnishes a means of photographing stress patterns in a bakelite specimen at predetermined intervals of time after an impact load is applied. The block diagram on page 6 is a simplified portrayal of the relative positions of the various units. The chain of events in the process is as follows:

1. The weight is dropped upon the lower bearing plate.
2. Upon striking the plate, the weight completes a 90 volt battery circuit which transmits a positive voltage pulse to the Time Delay Circuit.

3. The incoming pulse is delayed for the number of microseconds desired and fed through the amplifier curcuit to the trigger circuit.
4. The trigger circuit receives the delayed signal and causes a spark to bridge the electrode gap.
5. The spark is of sufficient intensity and duration to cause the film in an open-shutter camera to be exposed and to record the stress pattern existing at that moment.
6. By setting different time delays on the delay potentiometer, a series of photographs may be taken which will show the progressive change in stress in the specimen at various increments of time after impact.

BLOCK DIAGRAM



WEIGHT DROPPING MECHANISM

WEIGHT DROPPING MECHANISM

The arrangement and functioning of the equipment used to impose the axial, tensile impact load are fully illustrated and explained in the preceeding thesis by Messrs. Burke and Munninger.

E L E C T R I C A L U N I T S

TIME DELAY CIRCUIT

The function of this circuit is to delay the voltage pulse transmitted by the 90 volt battery circuit for a predetermined interval of time. The circuit is a one-shot multivibrator with a cathode follower tube to provide isolation.

The time delay feature of this circuit involves the use of a potentiometer by which a variable voltage may be added to the constant battery voltage pulse. These two voltages, coupled with the 210 volt D C power supply furnished, and the fixed values of condensers and resistors in the circuit govern the time of conduction of the output tube. When the output tube conducts, a voltage pulse is transmitted instanteously to the trigger circuit through the amplifier circuit.

The time delay circuit in use at present allows a variation in delay from 8 to 415 microseconds. The method of varying the time delay proposed by Messrs. Burke and Munninger, while permitting time settings of a smaller order than the present design, was not considered practical since it required complete recalibration of the time delay potentiometer for each different value of delay desired.

The present system involved a change in the arrangement of the circuit suggested by the previous authors, and a change in the values of some resistors and condensers.

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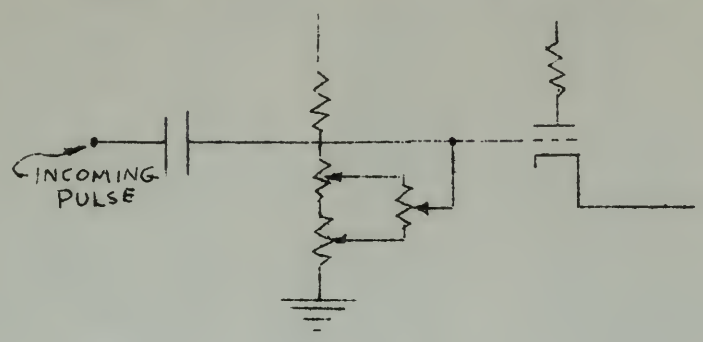
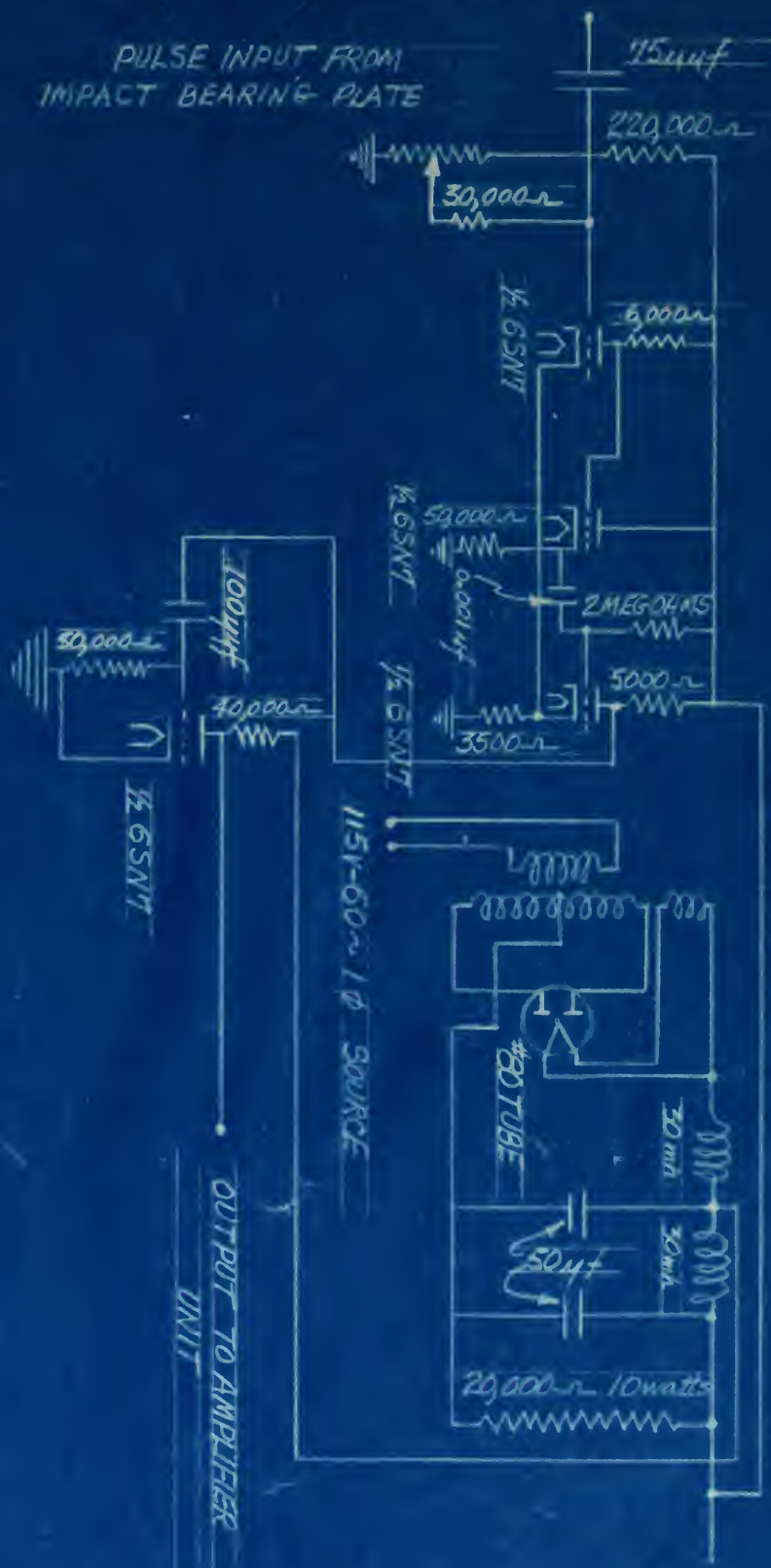
This method is suitable for continuous operation without recalibration. The following sketch is a diagrammatic representation of a suggested method that would permit finer time settings, if they should be required.



It was also found necessary to change the values of the resistor and the condenser in the differentiating gate leading to the output tube in order to increase the time that the output voltage pulse acted on the trigger circuit, and to increase the magnitude of the output pulse. The effect of time of duration of this pulse cannot be determined at present due to inherent difficulties in the spark gap delay, as explained in the section on the sparking unit.

TIME DELAY UNIT



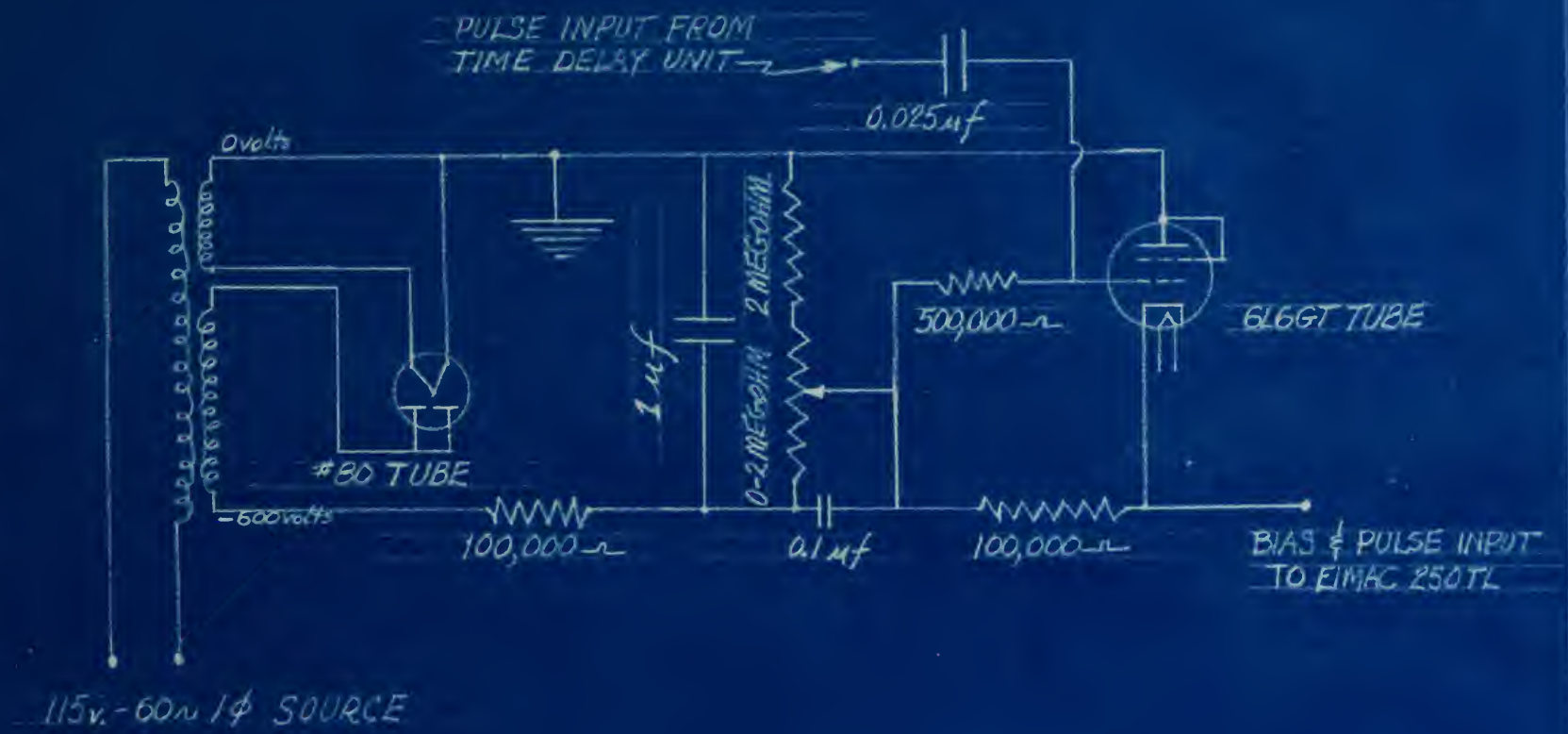
BIAS AND AMPLIFIER UNIT

Experimental results of the first test of the completed electrical circuits indicated that the 210 volt bias supply for the trigger circuit would be inadequate. The cut-off bias of the trigger tube (Eimac 250 TL) was found to be 280 volts, and the breakdown voltage was measured at approximately 210 volts. It was also found that it would be necessary to amplify the output voltage pulse of the time delay circuit in order to cause breakdown of the trigger tube.

A 600 volt D C half wave rectifier circuit was designed and constructed to provide the necessary bias. A 6L6GT Beam Power tube was incorporated in this circuit to provide the necessary power amplification.

Further experimentation with this new circuit indicated that the amplifier did not accomplish its purpose. Alteration of the time delay circuit differentiating gate, as discussed previously, provided the necessary voltage pulse. The "so-called" amplifier circuit was retained to provide a low impedance path for the voltage pulse between the time delay and trigger circuits.

BIAS AND AMPLIFIER UNIT



TRIGGER UNIT

As discussed in the preceeding thesis on this subject, the function of the trigger circuit is to cause the discharge of a condenser through a spark gap. The previous writers proposed a circuit developed by Mr. W. R. Plant and patented by the General Electric Company. The construction and testing of this circuit was one of the main problems confronting the authors of the present thesis.

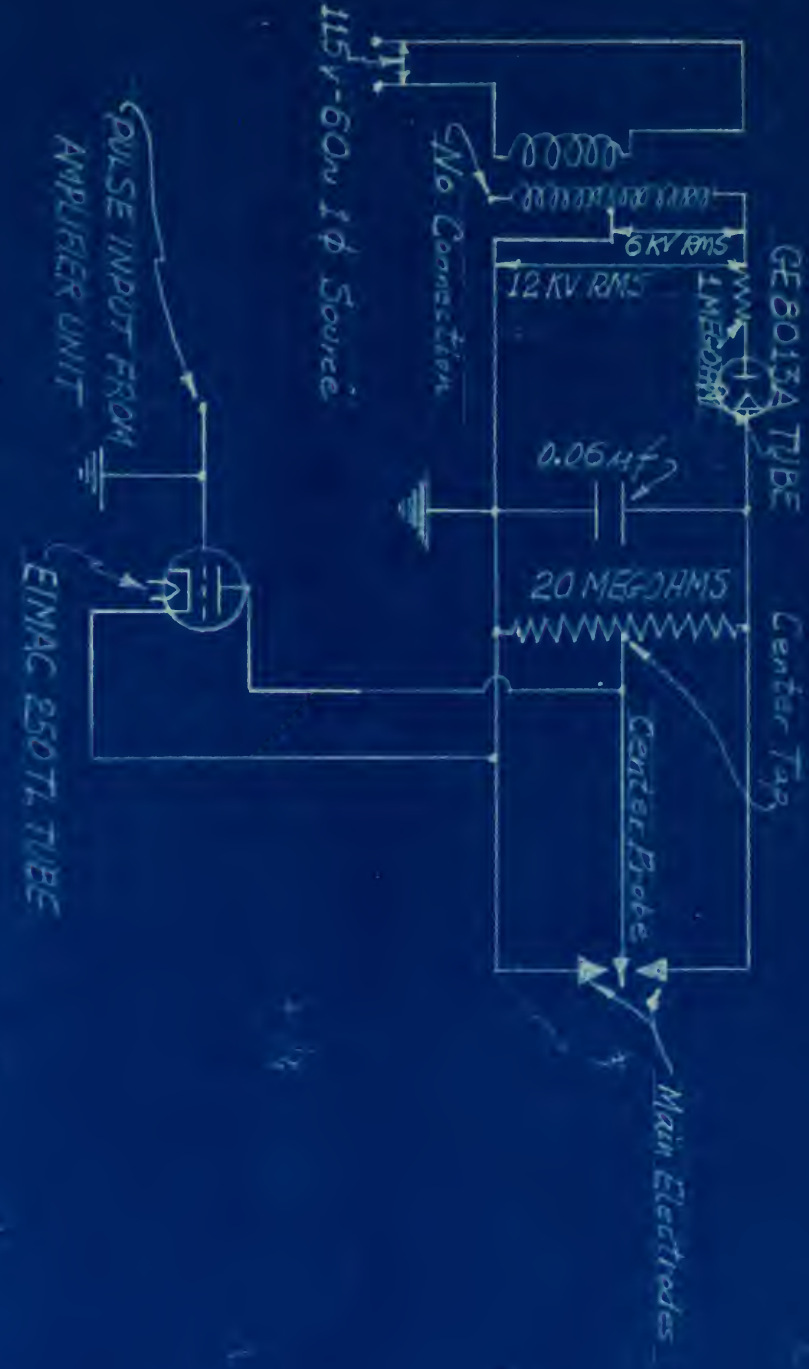
The original intent was to use a neon-tube transformer with a secondary voltage of 12,000 volts RMS. The circuit was tested. A spark was obtained, but the 1.0 meg-ohm resistor in the circuit heated up excessively. Investigation of the transformer showed that the secondary winding was center tapped to ground potential, and that in reality one-half of the secondary voltage, 6,000 volts, was being impressed across the resistor, and serving no useful purpose insofar as breakdown of the spark gap was concerned. To correct this condition it was proposed to insulate the transformer from the trigger circuit chassis. Before this could be undertaken, it was necessary to subject the transformer to a high voltage test to determine the breakdown voltage of the insulation. This voltage was found to be 8500 volts. The transformer was enclosed in a wooden box, constructed for the purpose, and mounted on insulators on the chassis. The supply voltage was reduced to a value to

produce 8400 volts across the secondary winding of the transformer. At this voltage the transformer arced to the box. For reasons of safety and convenience it was then decided to sacrifice the additional voltage, and to utilize the transformer at 6000 volts by using only one-half of the secondary winding.

The change to 6000 volts also eliminated another difficulty. The filament of the GE 8013A half-wave rectifier originally required a transformer insulated for 12,000 volts RMS. A 6000 volt circuit permits the use of commercially available transformers that are insulated at a 10,000 volt maximum. The transformer presently being used is the property of the Electrical Engineering Department and must be returned to that department.

In the construction of the original circuit it was found to be necessary to separate all high voltage leads from each other and any grounded metal parts of the circuit by approximately one inch. Failure to do this in the initial stages resulted in a corona discharge between leads and grounded portions, which caused improper operation of the circuit.

TRIGGER UNIT



SPARKING UNIT

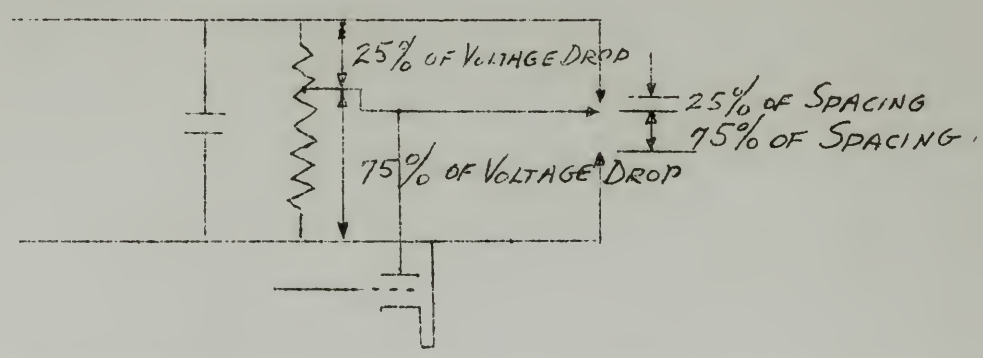
The sparking unit consists of a 0.06 microfarad condenser with high voltage, grounded, and center probe electrodes mounted directly on the condenser. The electrodes were mounted in this manner to reduce the inductance of the sparking circuit, and thereby the time of discharge of the condenser, to a minimum.

The electrodes used are of magnesium. The high voltage and grounded electrodes are cylindrical with a rounded point on the sparking end. The center probe electrode is a flat plate $\frac{1}{2}$" x 1" x $\frac{1}{4}$". The spacing between the center probe and the outer electrodes is approximately 3 millimeters.

Oscillographs of current across the spark gap indicate that the delay in sparking after breakdown of the trigger tube is of an order of 3 to 130 microseconds. This delay cancels any accuracy that is effected in the time delay circuit. Dr. L. Tonks of the General Electric Company has made an extensive study of this problem and recommends the shining of ultraviolet light on the high voltage electrode. Such a procedure should furnish enough free photoelectrons to initate a spark within 3 microseconds after triggering. It is believed that this 3 microsecond delay could be made constant and added to the time setting on the delay circuit when a photoelastic evaluation is made. A carbon arc or an iron arc with visible light rays filtered out could serve as

a source of ultraviolet. Dr. Tonks also recommends a high voltage electrode spaced slightly closer to the center probe than the low voltage electrode, and the use of electrodes of the shape of the center probe now in use, (ie) a rectangular shape with a length perpendicular to the spark of approximately eight times the thickness of the electrode. The present high voltage and grounded electrodes operate properly, but could possibly be improved by mounting washers on the body of each electrode to produce the desired rectangular shape.

The following sketch demonstrates a suggested method for impressing an increased voltage across the space between the center probe and the high voltage electrodes.



Such an arrangement would cause the high voltage to appear across 25% of the spark gap at the instant the trigger tube reached breakdown. A high overvoltage of this order would aid in stabilizing the time delay across the spark gap,

and probably would increase the intensity of light transmitted to the camera.

O P T I C A L U N I T

OPTICS

The optical unit is comprised of a focusing lens, polarizing plate, bakelite specimen, analyzer plate and a camera.

The light emitted at the spark gap is focused and passed through the polarizing plate, the stressed specimen, and the analyzer, thence to the film in the camera.

It was found to be desireable to focus the camera in line with the spark gap between the high voltage and center probe electrodes in order to obtain maximum light intensity.

Little work was done on the optical phase of the project because of the short period of time allotted.

OPERATING PROCEDURE

SEQUENCE OF OPERATION

1. Check that camera shutter is open and set at full aperture.
2. Focus camera.
3. Load film plate holder in camera.
4. Set proper electrode spacing on spark gap.
5. Set desired delay on delay circuit.
6. Insure that all electrical apparatus is properly grounded (Ground lead indicated on appartus.)
7. Turn on filament circuits for time delay and trigger units. (Bias circuit filament switching is combined with time delay
8. Allow 30 to 45 seconds for tube filaments to warm-up.
9. Completely darken room.
10. Energize high voltage circuit.
11. Remove film plate holder cover.
12. Release spring catches to drop weight.
13. Replace film plate holder cover.
14. De-energize high voltage circuit.
15. Turn off filament circuits.
16. Insure that spark gap condenser is properly discharged.
17. Steps 15 and 16 may be omitted if the film plate holder is reversed and another photograph is taken within a reasonable period of time.

PHOTOGRAPHY

PHOTOGRAPHIC TECHNIQUE

It was considered desireable to prove that the spark used would furnish sufficient light to produce the desired photographic results before continuing with further refinements of the weight dropping mechanism and the electrical units. Photographs of a bakelite specimen with a fixed applied load were taken for this purpose. The photographs shown on pages 38 and 39 are of frame specimen, and are sufficiently clear to indicate that a photoelastic study can be made.

No filter was used on these photographs, therefore monochromatic light was not obtained from the spark to the specimen. Messrs. Burke and Munninger recommended the use of a filter passing light of wavelength 4481Å. Although magnesium furnishes a light of this wavelength, the intensity of the light is so low that it is not felt that sufficient light will be available to take photographs. An attempt was made, however, to observe the relative light absorbing qualities of any filter by using a didynium filter with one photograph. The negative produced was too faint to print a good picture.

The following suggestions are made in the event such difficulty is encountered when the proper filter is used.

1. Use of a reflector mounted on the center probe of the spark gap in order to collect more light from the spark.
2. Use of increased developement time for prints,

increased aperture opening on the enlarger, and use of more sensitive photographic paper.

3. Use of a different metal for the sparking electrodes with a filter to provide monochromatic light for that particular metal.

4. It is not recommended to use increased development time for the film as this time is a critical value for high speed films.

The photographic technique and equipment used is as follows:

A. Photography.

1. Camera - Korona View, 5" X 7".
2. Aperture - Full opening.
3. Film - Triple S Pan, 5" X 7".

B. Film Development.

1. Materials - Kodak Dektol Developer, Agfa Acid Hypo.
2. Temperature of Baths - 66 to 70°F.
3. Operating Procedure.
   a. Place film in wash water bath for 10 to 15 seconds. Agitate continously.
   b. Place film in developer bath for 3½ to 4 minutes. Agitate for first 10 to 15 seconds.
   c. Rewash film in wash water bath for 10 to 15 seconds. Agitate continously.
   d. Place film in hypo bath for 15 minutes. Room may be lighted after film has been in hypo for 6 minutes.

e. Rinse film in running water bath for at least 10 minutes.

f. Allow film to dry thouroughly in racks (about 8 hours).

C. Print Development.

1. Photographic Paper - Kodabromide F2.

2. Enlarger Exposure Time - 20 seconds.

3. Enlarger Aperture Setting - f32.

4. Materials - MQ Universal Developer, Agfa Acid Hypo Stock Solution diluted 1 part to 2 parts of water.

5. Procedure.

a. Expose paper for 20 seconds.

b. Place paper in wash water for 10 to 15 seconds.

c. Place in developer for 45 seconds. Rub face of paper lightly with the fingers during this time.

d. Wash paper in water for 10 to 15 seconds.

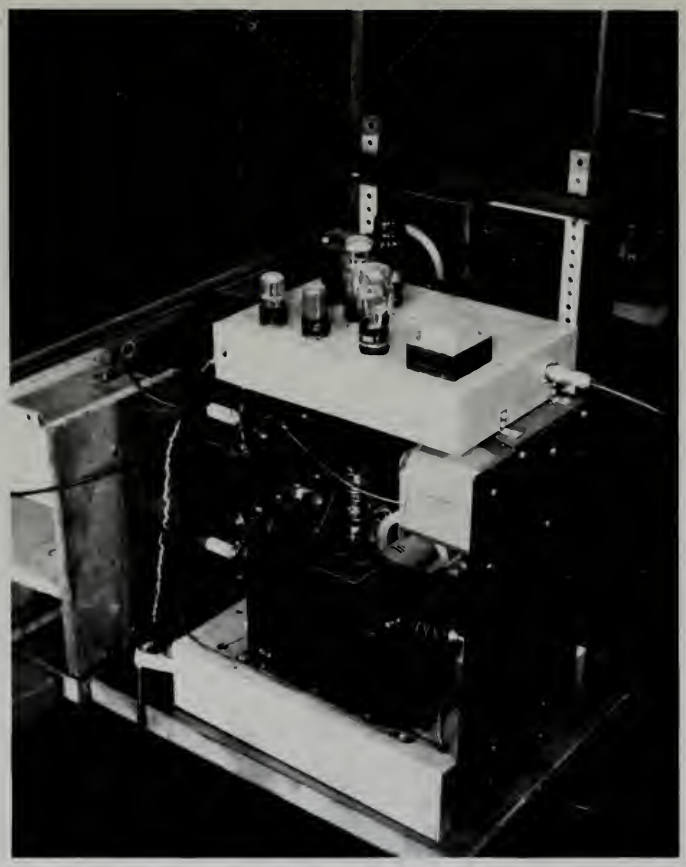
e. Allow paper to set in fixer for 8 to 10 minutes.

f. Place paper in running water bath for at least one hour.

g. Dry paper by blotting or use of a commercial dryer.

The procedures followed were not those recommended by M. M. Frocht in his book "Photoelasticity". It was considered that commercial development procedures should be

I L L U S T R A T I O N S

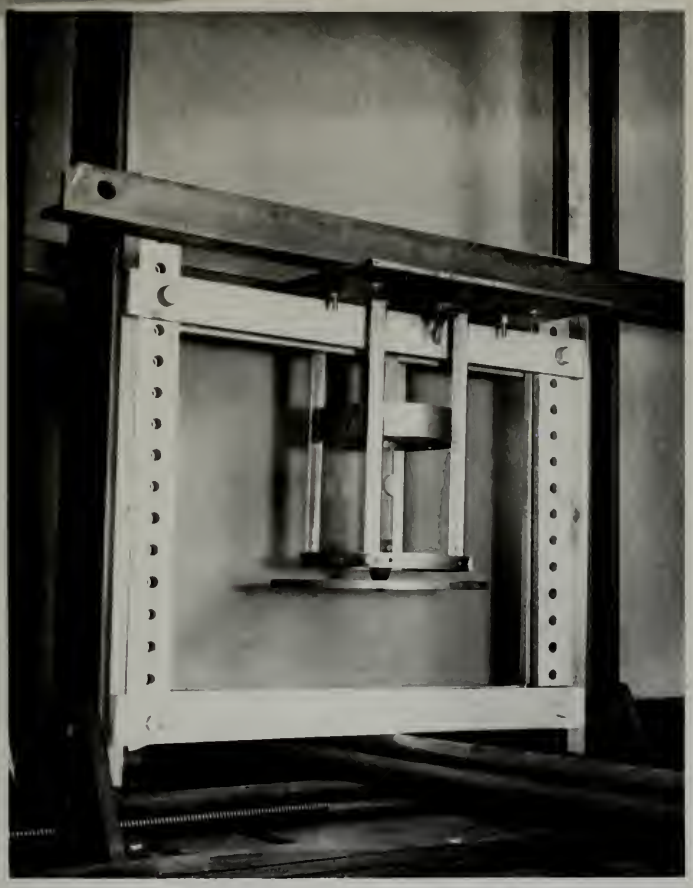


PHOTOGRAPH OF THE ENTIRE ASSEMBLY

This photograph of the completed assembly shows the entire mechanism for obtaining photoelastic pictures of impact stresses.

The component parts of the device are illustrated and explained separately on the following pages.

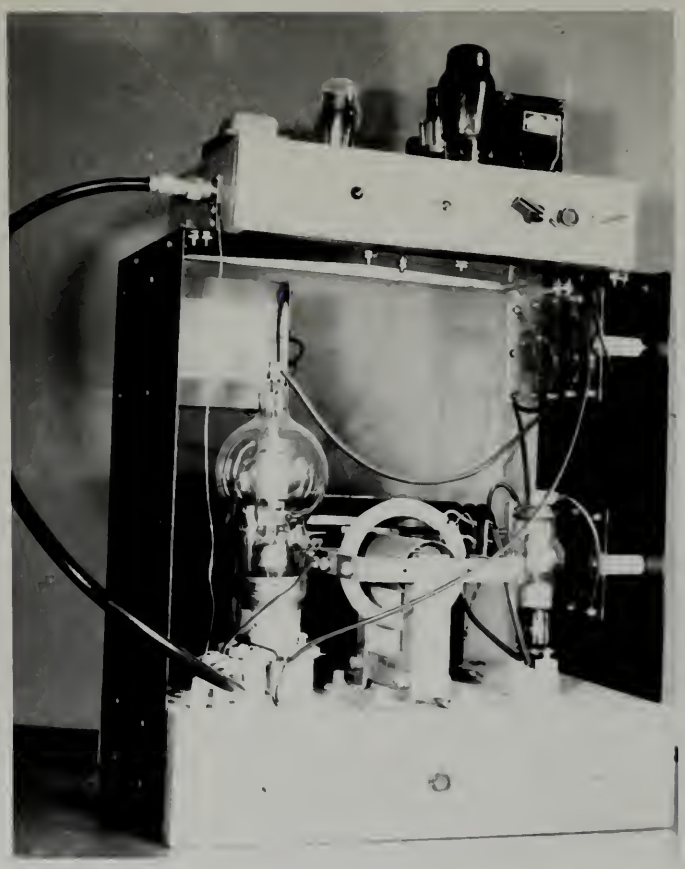
WEIGHT DROPPING MECHANISM



The two views of this mechanism show the weight in the dropping and the dropped positions.

The weight is allowed to fall by releasing the spring catches on the upper plate. It is guided while dropping by the four vertical posts which fit into circumferential grooves cut into the weight. This insures that the weight is in a horizontal position when it strikes the lower bearing plate.

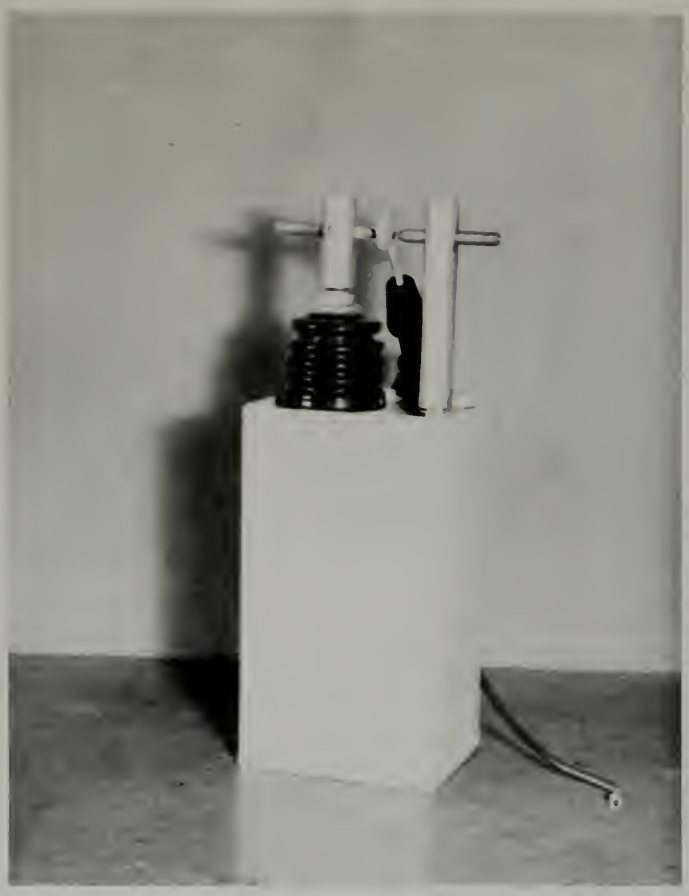
At the instant of striking the lower plate, a tensile, axial impact load is applied to the specimen, and a 90 volt DC battery circuit is closed. The completion of the battery circuit supplies the initial voltage pulse to the time delay circuit.



FRONT VIEW OF ELECTRICAL CIRCUITS

The final assembly of the electrical circuits consists of the upper chassis which contains the time delay and bias and amplifier circuits, and the lower chassis which contains the trigger circuit, except for the spark gap condenser and sparking electrodes. The voltage pulse from the upper circuits is transmitted through a coaxial cable to the lower trigger circuit.

The object attached to the left side plate is the filament transformer for the trigger tube, and the two boards on the right plate are the 1.0 and 10.0 meg-ohm resistors in the trigger circuit.

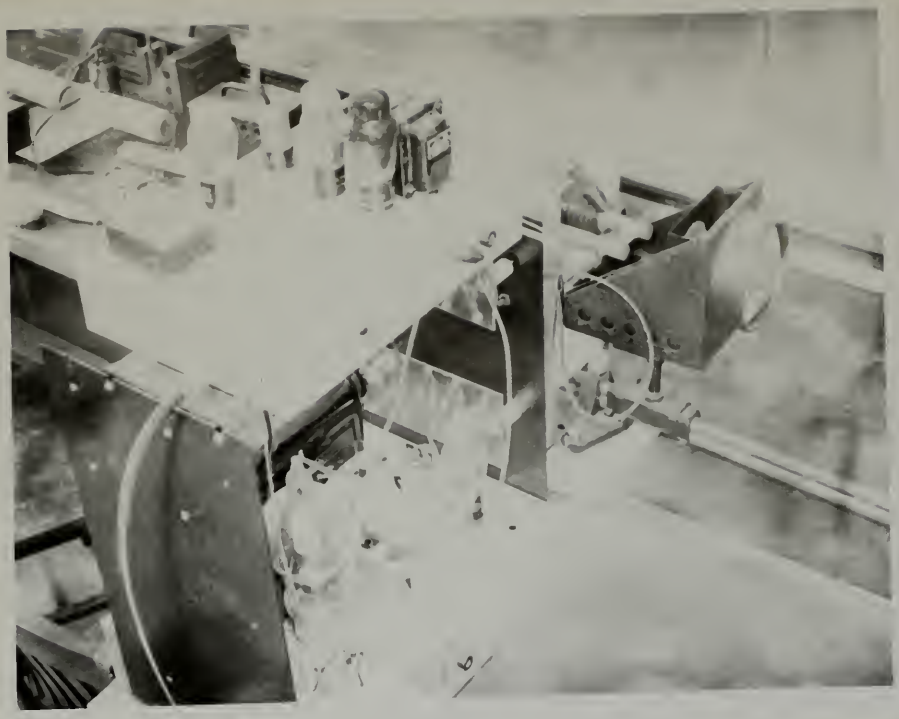


ARRANGEMENT OF SPARK GAP

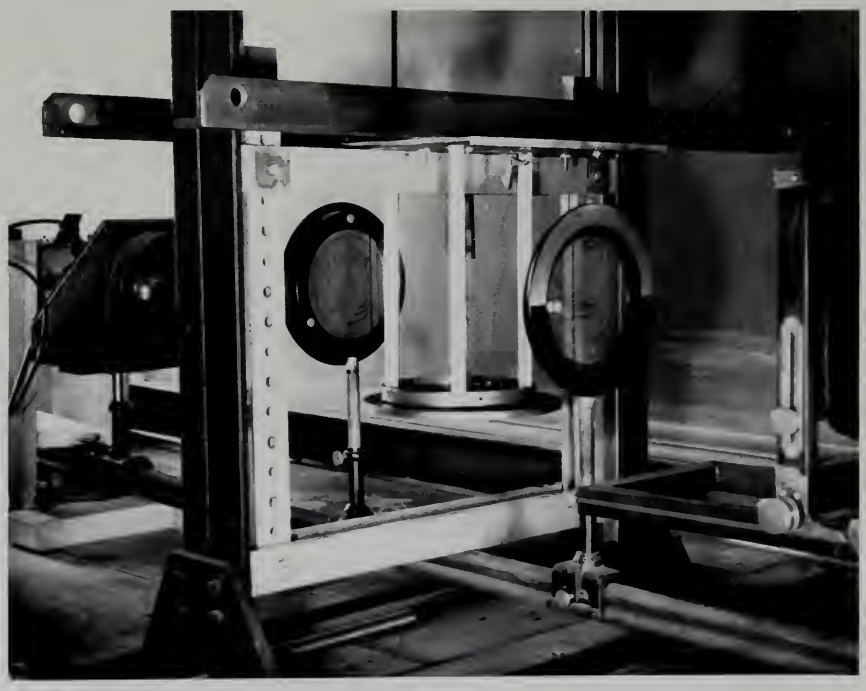
The details of mounting the spark gap electrodes on the spark gap condenser are important. The electrode holders are mounted directly on the terminals of the conderser in order to eliminate the inductance that would have been caused by long leads.

The size of the gap may be varied by moving the center probe electrode and by turning the threaded, grounded electrode.

When the trigger tube receives a voltage pulse, the center probe is lowered to ground potential, and a spark forms across the gap.



ELECTRICAL CIRCUIT, SPARK GAP, AND FOCUSING LENS



FOCUSING LENS, POLARIZERS, SPECIMEN, AND CAMERA

The light emitted by the spark is passed through the focusing lens to the polarizer, through the specimen, and out of the analyzer to the film plate in the camera.

CAMERA

The camera used is a 5" X 7" Korona View borrowed from the Physics Department of Rensselaer Polytechnic Institute.

The camera was mounted with its lens and film plate holder in line with the light source. Photographs were taken in a darkened room with an open camera shutter.

PHOTOGRAPHS TAKEN OF A BAKELITE SPECIMEN
UTILIZING LIGHT FROM THE SPARK GAP.

RESULTS

This thesis carried forward the work commenced by Messrs. Burke and Munninger. The present authors designed and constructed additional equipment, and reconstructed portions of the existing apparatus. It is felt that the original method proposed by Messr. Burke and Munninger is fundamentally sound, and with the additions and refinements contributed by the present authors, can be used to commence a study of impact stresses by photoelastic analysis.

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